Table 41: TBL-NPV Results for Each Feature by Impact Type, Central Station/Civic Space Park/Taylor Mall

Impact Type	Cost/Benefit	Mean Value	95% Confidence Interval		
Financial	Capital Expenditures	**-$576,502**	-$915,078	to	-$253,456
Financial	Operations and Maintenance	**-$153,037**	-$202,970	to	-$106,861
Financial	CapEx on Additional Detention	**$0**	$0	to	$0
Financial	O&M on Additional Detention	**$0**	$0	to	$0
Financial	CapEx on Additional Piping	**$0**	$0	to	$0
Financial	O&M on Additional Piping	**$0**	$0	to	$0
Financial	Replacement Costs	**-$333,981**	-$617,912	to	-$41,247
Financial	Residual Value of Assets	**$49,228**	-$73,487	to	$180,993
Social	Heat Island Effect (Mortality)	**$333,713**	$114,609	to	$558,548
Social	Heat Island Effect (Morbidity)	**$598**	-$1,891	to	$3,301
Social	Flood Risk	**$65,457**	$65,457	to	$65,457
Social	Property Value	**$8,354**	$4,164	to	$12,335
Environmental	Water quality	**$92,319**	-$48,719	to	$255,721
Environmental	Carbon Emissions from Concrete	**$281,536**	$117,296	to	$514,838
Environmental	Air Pollution Reduced by Vegetation	**$31,586**	$19,487	to	$43,357
Environmental	Carbon Reduction by Vegetation	**$3,114**	-$1,117	to	$8,109
Environmental	Air Pollution from Energy Use Reduction	**$14,608**	-$2,555	to	$34,417
Environmental	Carbon Emissions from Energy Use Reduction	**$12,173**	-$9,902	to	$38,542

Total	**Triple Bottom Line NPV**	**-$170,834**	-$1,552,617	to	$1,314,054

6 Stakeholder and Policy Consideration

This section was co-authored by Watershed Management Group and The Nature Conservancy and provides an overview of the policy opportunities based on the results of this report and potential steps forward for considering Triple Bottom Line benefits in City of Phoenix projects. City of Phoenix codes and ordinances have been reviewed and are listed below in Section 6.4. The results of the Autocase report justify evaluation of the Triple Bottom Line benefits in project alternatives and the recommendations below provide steps to do that.

6.1 Correlate multiple benefits to City departments & City sustainability goals

It is recommended to clearly communicate the results of the study to relevant departments and stakeholders, as well as to encourage stakeholder involvement and participation. Table 42 lists the co-benefits identified in the study and some of the relevant City and County stakeholders likely to receive those benefits.

Table 42: TBL-NPV: Co-benefits and relevant City and County stakeholders

Co-benefit Identified in the CBA	Benefiting Department(s)
Heat mitigation	Parks and Recreation Department; Office of Homeland Security and Emergency Management; Transit Department; Street Transportation Department; Human Services Department; Office of Sustainability
Flood risk reduction	Planning and Development Department; Office of Homeland Security and Emergency Management; Street Transportation Department (flood-related maintenance), Public Works Department (Floodplain management); Flood Control District of Maricopa County
Carbon emissions	Office of Environmental Programs; Office of Sustainability; Public Works Department
Water quality improvement	Office of Environmental Programs; Water Services Department
Air pollution	Public Works Department; Office of Environmental Programs; Office of Sustainability, Maricopa County Department of Air Quality
Property value uplift	Community and Economic Development, Public Works Department
Health (heat morbidity / mortality)	Maricopa County Department of Public Health

The list above is incomplete, but it provides a starting point for determining which departments may be interested in the results of the study, which co-benefits may carry the most weight, and which department budgets can be tracked to identify any cost offsets or long-term value revealed by the analysis. It is important to communicate the long-term value (in terms of NPV and TBL) of investments in GI/LID to the public, developers, and building owners.

Identifying co-benefits received by specific stakeholders may provide incentive for cost-sharing or co-investment. Departments whose goals are shown to be met in the TBL-CBA might contribute to sharing costs, as might members of the private sector.

The City of Phoenix has identified short and long-term sustainability goals. Table 43 identifies sustainability goals, achievement of which may be aided by the application of GI/LID.

Table 43: TBL: Sustainability Goals related to the GI/LID

Related 2050 Sustainability Goal(s)
Having all residents within a five-minute walk of a park or open space by reducing the urban heat island effect through green infrastructure as well as doubling the current tree and shade canopy to 25% and adding 150 miles of paths, greenways.
Reduce carbon pollution from vehicles, buildings, and waste by 80%-90%.
Provide a clean and reliable 100-year supply of water by reducing dependence on potable water supplies for irrigation and improving water quality downstream of stormwater outfalls
Phoenix will achieve a level of air quality that is healthy for humans and the environment. This includes outperforming all federal standards and achieving a visibility index of good or excellent on 90% of days or more.

6.2 Ensure asset management processes incorporate a broad range of benefits and costs from a TBL perspective in evaluating project alternatives

Many leading utilities and municipalities now explicitly incorporate a range of costs and potential financial, social, and environmental benefits (TBL) when identifying and evaluating project alternatives. Incorporating TBL into asset management has allowed municipalities to deliver projects with amenities and services desired by the public. Two measures the City could implement to incorporate a TBL philosophy are:

- Investigate options for GI/LID early in the planning phase of CIP projects. Cultivate a shift from opportunity-based to need-based projects that will provide the largest TBL benefits. Prioritization of project types and identification of suitable locations for those project types can help with this shift.
- Develop a mechanism for combining revenue sources across departments to encourage implementation of alternatives that provide a greater value when the multiple benefits are calculated. In consultation with the benefiting departments, the City may consider creating an interdepartmental team charged with assembling such a mechanism with accountability to the city manager or council.

6.3 Prioritize by project type and suitability

Based on the results of this study and others in the southwest (i.e., Watershed Management Group studies of Tucson's Airport Wash Area and Sierra Vista) it is clear that the most sustainable and cost-effective GI/LID retrofit projects have minimal impacts on existing concrete and asphalt. The results show that infrastructure and new projects that utilize natural systems like swales, infiltration basins and trenches have a higher TBL value and avoiding pervious pavers, porous concrete and asphalt is recommended unless they provide an irrigation benefit for shade-producing landscapes or the flood mitigation benefits are required for the project. As such, it is recommended that the City adopt the following prioritization policy when identifying GI/LID project opportunities to maximize the triple bottom line benefits:

- Prioritize natural GI/LID systems (swales, infiltration basins and trenches) in new development
- Prioritize open space and parks for GI/LID retrofits[4] to minimize the need for hardscape removal
- For GI/LID retrofit projects that involve hardscape removal, prioritize projects where there are already plans to fully reconstruct and rebuild the hardscape infrastructure.

6.4 Consider revisions to existing codes and plans

The following is a brief outline of general opportunities to promote GI/LID more broadly throughout a range of City policies, plans, standards and codes. Additional study is needed to refine and prioritize these recommendations:

- *General Plan*
    - In Stormwater section include planning to identify, prioritize, and target areas for new and retrofit GI/LID opportunities
- *Tree and Shade Masterplan*
    - Integrate GI/LID as critical infrastructure to reduce or eliminate outdoor water use in native landscapes while creating a more robust tree canopy
    - Move beyond iTree stormwater benefits of trees by using GI/LID
- *2013 COP Stormwater Policies and Standards*
    - Consider incentives to distribute retention across site
    - The drainage plan design phase for a project should include goals to incorporate GI/LID (e.g., using runoff from impervious surfaces to support vegetation, percent canopy cover for the project area, and utility planning to avoid landscape drainage areas).
    - Emphasize natural channel design practices (not hardening channels but allowing infiltration)

[4] Utilizing stormwater runoff from adjacent landscapes, roads and hardscapes in open spaces and parks (because they don't require hardscape removal) with GI/LID features

6.5 Create a Roadmap

The table below provides a roadmap with general recommendations for mainstreaming GI/LID projects with multiple benefits.

Table 44: Recommended Action and Steps

1. Consult resources, especially EPA's "Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs".
2. Involve stakeholders: Clearly communicate the results of the study and address questions of City staff and stakeholders that are answered by the study.
3. Determine whether co-benefits are shared by specific stakeholders and whether those stakeholders may have interest in cost-sharing or co-investment. Consider developing a reserve to provide incentives to implement GI/LID based on site context.
4. Decision-makers at the project level should consider life-cycle costs and net present value from a TBL perspective including community benefits such as flood risk reduction, water quality improvements, air pollution reduction, and heat island mitigation.
5. Work across relevant departments to identify and implement GI/LID in CIP projects, including their maintenance, utilizing the reserve fund (if instituted) to ensure successful implementation. Identify and accommodate new maintenance activities for GI/LID to provide improved NPV, cost-savings, and TBL benefits, including equipment and skill sets.
6. Identify and remove barriers to installation of features that provide a specific threshold for public services or positive NPV (See City of Phoenix Code Review to Promote Green Infrastructure – Case Study)[5]
7. Implement procedure for easy or fast-tracked permitting of private projects with GI/LID components that deliver benefits to the broader community
8. Develop technical guides for residents, businesses, etc. on incorporation of GI/LID into designs, calculation of net present value of benefits. Include information on resources to assist with implementation.
9. Measure and assess performance and costs: Continue to track annual maintenance costs of specific features. Measure performance of installed features for heat reduction, flood mitigation, water quality improvements, and other benefits described in the study. Apply cost-benefit data from the Cost Benefit Analysis to Stormwater Management Models of distributed LID to assess TBL for achieving specific goals related to air quality, flood mitigation, and heat risk reduction.
10. Investigate options for GI/LID options as early as possible in the planning phase of CIP projects. Cultivate a shift from implementing projects which are strictly opportunity-based to integrating need-based projects that will provide the largest benefits. Develop a list of priority areas for LID projects, such as in areas with high heat vulnerability or in areas with localized flooding.

[5] https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/PHX_Code review to promote green infrastructure case study.pdf

6.6 Resources:

The following resources are available on how other cities have initiated a GI program and managed their assets, which may provide useful information for the City:

1. EPA Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs (2013)[6]
2. Philadelphia Combined Sewer Overflow Long Term Control Plan Update, Supplemental Documentation Volume 2, Triple Bottom Line Analysis[7]
3. Urban Land Institute. Harvesting the Value of Water: Stormwater, Green Infrastructure, and Real Estate [8]
4. Seattle Public Utilities Triple Bottom Line Analysis Guidebook[9]
5. Forthcoming study on developing a Green Infrastructure Fund for the City of Tucson

Existing and upcoming documents that provide information on the state of GI policy in Phoenix (in addition to this cost-benefit study) include:

1. City of Phoenix Code Review to Promote Green Infrastructure – Case Study[10] (complete)
2. Green Infrastructure Barriers and Opportunities in Phoenix, Arizona[11] (complete)
3. GI/LID Effectiveness Study (in progress as of June 2018)
4. Identifying Key Areas in the City of Phoenix for Infiltration and Retention Using Low Impact Development – The Nature Conservancy and Bureau of Reclamation (in progress as of June 2018)
5. Guidelines and specifications for GI/LID in Maricopa County – Sustainable Cities Network (in progress as of June 2018)

[6] https://www.epa.gov/sites/production/files/2015-10/documents/lid-gi-programs_report_8-6-13_combined.pdf
[7] http://www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf
[8] https://americas.uli.org/wp-content/uploads/sites/125/ULI-Documents/HarvestingtheValueofWater.pdf
[9] https://tnc.app.box.com/s/hylxegjvfxsl11o8dhqw8gdoktpte01h
[10] https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/PHX_Code review to promote green infrastructure case study.pdf
[11] https://www.epa.gov/sites/production/files/2015-10/documents/phoenix_gi_evaluation.pdf

7 Conclusions and Caveats

7.1 Conclusion

This short discussion is meant to start the longer conversation of understanding *who* may benefit from GI/LID and *how* these types of multi-account analyses can be used as a tool to galvanize stronger stakeholder buy-in. Breaking down the costs and benefits of GI/LID by each impact type – whether that impact is purely financial or not – provides valuable insights.

Firstly, it enables greater understanding of who may be benefiting from non-traditional forms of capital planning. By thinking of which stakeholders would benefit from each impact, it allows the City to:

1) Assess what existing policies can be leveraged to support GI/LID, as well as how GI/LID may promote the goals of those policies, and
2) Communicate results in a way that gets maximum buy-in from various agencies and external stakeholders. By showing that these projects are aligned with the broader goals of each respective stakeholder, the potential hurdles that often come with more cost-intensive projects can be addressed early.

Multi-account results not only answer the question of "Who benefits?" but equally important, "How much do they benefit?". Providing monetized results across the financial, social, and environmental spectrum enables users to look at projects in a more holistic way, and crucially allowing that holistic analysis to be on an apples-to-apples basis i.e. in dollar terms. Whereas before, we may have only been able to qualitatively state that urban heat island benefits would be generated, we can now put a dollar value to that benefit and compare it against any financial impact. The ability of knowing who benefits and how much they benefit is a powerful tool to build consensus to the delivery of projects and creates an evidence base to promote a shared responsibility to capital planning for these non-traditional projects. The ability to see that the burden of operations and maintenance of a project may fall upon one agency, while creating savings for another agency may provide the impetus for cost sharing.

Finally, these types of analyses give visibility into which features are providing the greatest benefits in terms of the city's priorities. It offers a quick breakdown of where the greatest impacts (whether a cost or benefit) are occurring and enables the City to start thinking of how those impacts can either be mitigated or improved upon. For example, we can see that replacement cost plays a large factor in the financial dis-benefits of the Central/Civic/Taylor project; therefore, by focusing on ways to reduce this replacement cost may mitigate that financial burden. Alternatively, we can see that swales may provide greater urban heat island benefits than Bioretention Basins. Given the heat stress Phoenix faces, users can utilize these types of results to prioritize projects that have the largest impact on that element.

Ultimately, assessing projects across a spectrum of impacts and valuing them in dollar terms allows the City to map benefits and costs to various stakeholders and is an important step toward consensus-building and developing a business case in a way that everyone can understand.

7.2 Caveats

This report is a starting point that can help focus the City's GI/LID efforts to those features more likely to provide long-term value. There are some limitations that should be noted before making policy decisions:

- There is limited local data on CapEx and O&M costs, since this is a fairly recent initiative in Phoenix. We have used a small sample size for Phoenix-specific costs (and partial data for the Central Station/Civic Space Park/Taylor Mall project which led to more estimation on that site), which were supplemented by national averages. Once additional GI/LID projects are completed, a greater inventory of cost information will be available to be refined and make more informed estimates for improved recommendations.
- Replacement costs are based on US-averages; depending on maintenance of the City, as well as local stressors from weather etc., these replacement costs may vary. Nevertheless, we have included low and high estimates to offer a range to reflect this uncertainty.
- The Concrete base case was based on concrete sidewalk or plaza versus roadway and does not include any costs associated with roadbed, grading, and other elements that the street manual requires. As such, the base case likely underestimated costs, including costs of compliance with other required specifications such as grey stormwater infrastructure. The study attempted to capture this through "CapEx and O&M on additional detention and piping" but it is an estimate that could be refined with further analysis and information.
- The above concern also applies to O&M of concrete; stormwater-related O&M costs of a concrete surface need to be included, such as catch basin cleaning (water quality & flooding purposes), stormwater pipe cleaning (flooding). This has been captured to an extent within the water quality estimate (see Methodology Section 8.3.3.4) but could also be refined with further analysis.

8 Methodologies

8.1 TBL-CBA Framework

This project was conducted using a Triple Bottom Line Cost Benefit Analysis (TBL-CBA) framework. TBL-CBA provides an objective, transparent, and defensible business case framework to assess investments in stormwater infrastructure. The proposed analysis broadens traditional financial analysis to incorporate, and value social and environmental factors within an expanded CBA framework. The intent of these analyses is to determine the social and environmental benefits (and dis-benefits), in addition to the lifecycle financial costs and avoided costs that arise from projects.

CBA is a conceptual framework that quantifies in monetary terms as many of the costs and benefits of a project as possible and converting them all into a present day dollar value. In CBA, a "base case" (the existing conditions) is compared to one or more alternatives (which have some significant improvement compared to the base case). The analysis evaluates incremental differences between the base case and the alternative.

To incorporate uncertainty into the analysis, Autocase runs a Monte Carlo based simulation of the possible outcomes and final project value. Low, Expected, and high values are taken from both user inputs and values in literature to reflect the underlying uncertainty in the values used in the CBA. These values are then defined by a distribution and applied to the benefit-cost analysis. This process is then repeated thousands of times to create a probability distribution of the results in the CBA – or 95% confidence intervals, allowing for a more nuanced assessment of project risks.

8.2 Base case

As always with Cost Benefit Analysis (CBA), it is important to factor in the base case – i.e. what would have been built on this site if this feature type were not built? This is vital so that we can estimate the *incremental* benefit from LID, and not just the total benefit.

After discussion with Phoenix staff, the base case feature type used is concrete to reflect the impervious nature of common infrastructure choices. Therefore, when estimating the value of each GI/LID feature type, we compared the benefits versus this 'concrete' feature type for the general feature analysis. Base cases for the case study sites were specific to each site in collaboration with City of Phoenix staff.

8.3 Valuation Methodologies

Autocase automatically values the triple bottom line benefits (or dis-benefits) of numerous impact types. For this assessment, Autocase was used to value:

- Capital expenditure;
- Operations and maintenance costs;
- Replacement costs;
- Residual value;
- Avoided piping and detention costs (both CapEx and O&M)
- Heat Island Effect on both mortality risk and morbidity risk;
- Flood risk;
- Property value uplift;
- Water quality;
- Avoided carbon emissions from concrete;

- Air pollution and carbon emissions reduced by vegetation; and
- Air pollution and carbon emissions reduced by energy savings.

8.3.1 Financial

8.3.1.1 Capital Expenditure

The capital costs for each of the features were based off City of Phoenix and Watershed Management Group project costs that have either been built or are in design, thus representing a local picture of the upfront costs of each of these feature types. For the general feature analysis, because local data was limited (often to only one project's cost), national data was used to supplement local data as needed using EPA SUSTAIN, and National Stormwater Management Calculator and low, expected, and high estimates were put in for each to allow for a risk assessment. Costs were converted into a standard 'per 1,000 square feet' cost. The case studies used project-specific data wherever possible. There were a few gaps in project cost data for the case studies and national data was used to fill in as needed.

8.3.1.2 Operations and Maintenance

Operations and maintenance (O&M) costs are those that accrue throughout the life of the project. In Autocase, they are discounted to produce a present value of the costs. As with capital costs, local O&M costs were provided by the City of Phoenix and Watershed Management Group wherever possible, and for features that did not have costs, Autocase was supplemented with the Green Values Stormwater Toolbox and low, expected, and high estimates were put in for each to allow for a risk assessment. This method was used for both the general features analysis and the case study analysis.

Watershed Management Group O&M costs in this report were determined with five WMG projects: Primera Iglesia in Phoenix and the 4 demonstration sites in Tucson. WMG has two years of maintenance data at Primera Iglesia from 2014-2015 and three years of data at the Tucson demonstration sites from 2014-2017. Site maintenance activities at all sites include sediment removal, weed removal, pruning vegetation and trees, mulching material onsite by hand and trash removal and plant replacement. Maintenance at all sites is a combination of WMG staff and volunteer labor. At Primera Iglesia, volunteer labor was not quantified. At the 4 WMG sites in Tucson, volunteer and staff labor is tracked electronically. Volunteer labor is quantified at 25% efficiency of a regular trained staff hour, so any volunteer labor hours were converted to an equivalent trained employee hour. Labor hours were tracked and then multiplied by the average City of Phoenix landscape maintenance contractor costs of $75/hr. There was 185 hours of maintenance over three years across the four sites (spanning 38,209 sq ft) – equating to 62 hours per year, or 1.6 per 1,000 sq ft. At $75/hr, this comes to $120 per 1,000 sq ft.

A summary of the CapEx and O&M costs are given in the table below. A detailed description of each cost is given in the description for each feature type and site.

Table 45: Summary of Feature Costs

Feature	Unit		Cost ($)		
			Low	Expected	High
Concrete	CapEx	$ per 1,000 sq ft	$4,500	$5,750	$7,000
	O&M	$ per 1,000 sq ft	$0	$0	$0
Swale	CapEx	$ per 1,000 sq ft	$1,124	$5,527	$11,358
	O&M	$ per 1,000 sq ft	$97	$120.95	$151
Porous concrete	CapEx	$ per 1,000 sq ft	$6,370	$7,000	$10,670
	O&M	$ per 1,000 sq ft	$12	$24	$48
Bioretention basin	CapEx	$ per 1,000 sq ft	$2,000	$3,000	$4,000
	O&M	$ per 1,000 sq ft	$97	$121	$151
Infiltration trench	CapEx	$ per 1,000 sq ft	$400	$1,450	$4,200
	O&M	$ per 1,000 sq ft	$97	$121	$151
Pervious pavers	CapEx	$ per 1,000 sq ft	$7,540	$12,970	$17,800
	O&M	$ per 1,000 sq ft	$12	$24	$48
Underground stormwater storage	CapEx	$ per 1,000 cubic foot	$904	$1,205	$1,506
	O&M	$ per 1,000 cubic foot	$1	$1	$6
Trees	CapEx	$ per tree	$160	$591	$739
	O&M	$ per tree	$12	$16	$20
Planter boxes	CapEx	$ per 1,000 sq ft	$550	$8,000	$24,500
	O&M	$ per 1,000 sq ft	$97	$121	$151
Retention basin	CapEx	$ per 1,000 cubic foot	$4,260	$11,550	$22,710
	O&M	$ per 1,000 cubic foot	$15	$30	$60
Porous asphalt	CapEx	$ per 1,000 sq ft	$2,840	$6,330	$9,470
	O&M	$ per 1,000 sq ft	$12	$24	$48
Shrubs	CapEx	$ per 1,000 sq ft	$109	$218	$355
	O&M	$ per 1,000 sq ft	-	-	-

Notes:

- **O&M for shrubs is included within the O&M cost of other features.**

8.3.1.3 Replacement Costs and Residual Value of Assets

Whether the infrastructure is a tree, a Bioretention Basin, a green or traditional roof, or plain concrete, all elements of an infrastructure project need to be replaced at some point. All features types have different lifespans, as well as different costs of replacement at the end of their operating lives. Autocase quantifies these costs as the lifetime "Replacement Costs" of each feature. Replacement costs for features are estimated whenever the expected operating duration of the project exceeds the lifespan of a feature. Replacement costs are then combined with the expected lifespans of each feature type and the operating life of the project to quantify the expected total replacement costs.

Autocase estimates replacement costs as a percentage of initial capital expenditure (using the values listed above). The percent replacement costs are gathered from the EPA's SUSTAIN database. As for useful lives, they are estimated from a number of sources. These sources are used to create a distribution in duration of useful life for each feature type. Sources used include Center for Neighborhood Technology (2006), Toronto and Region Conservation Authority (2013), and City of Toronto (Belanger, 2008).

Table 46: Replacement Costs and Useful Life of Features

Feature	Replacement Cost (% of original)			Useful Life (years)		
	Low	Expected	Max	Low	Expected	Max
Concrete	24	62	100	20	31	50
Swale	41	64	90	20	35	50
Porous concrete	49	74	100	20	28	30
Bioretention Basin	41	64	90	19.99	20	20.01
Infiltration trench	15	17	20	5	10	15
Pervious pavers	66	78	100	20	25	30
Underground stormwater storage	41	64	90	20	34	50
Trees	100	100	100	25	50	75
Planter boxes	41	64	90	5	20	30
Retention basin	41	64	90	25	38	50
Porous asphalt	46	73	100	15	24	30

When a project's operating life comes to an end, many assets may still have an implicit residual value. Depending on the remaining useful life of the asset for each alternative, at the end of the study period, some site elements have a "residual value". The residual value was calculated by determining the assets' useful lives remaining at the end of the period and determining an appropriate value of the asset based on its remaining useful life. Autocase estimates this residual value by assuming straight-line depreciation in the value of all assets/design features. This value is then discounted into present value terms.

8.3.2 Social

8.3.2.1 Heat Island Effect (Mortality)

Heat waves are an increasing danger across North America, occasionally resulting in large numbers of premature deaths. These events may be more frequent and severe in the future due to climate change. GI/LID can reduce the severity of extreme heat events by creating shade and reducing the amount of heat absorbed by pavement and rooftops. Even a small cooling effect can be sufficient to reduce heat stress-related fatalities during extreme heat wave events.

The Urban Heat Island (UHI) effect compromises human health and comfort by causing respiratory difficulties, exhaustion, heat stroke, and heat-related mortality. Various studies have estimated that trees and other vegetation within building sites can reduce temperatures by 5 °F when compared to outside non-green space. At larger scales, variation between non-green city centers and rural areas has been shown to be as high as 9 °F during the day and up to 22 °F during the night.

To quantify heat risk mitigated in Autocase, the first step is determining reduced temperatures in the area because of the project. Figure 34 shows various feature types and the average temperature reduced caused by changing a hypothetical city of all asphalt to that specific feature instead.

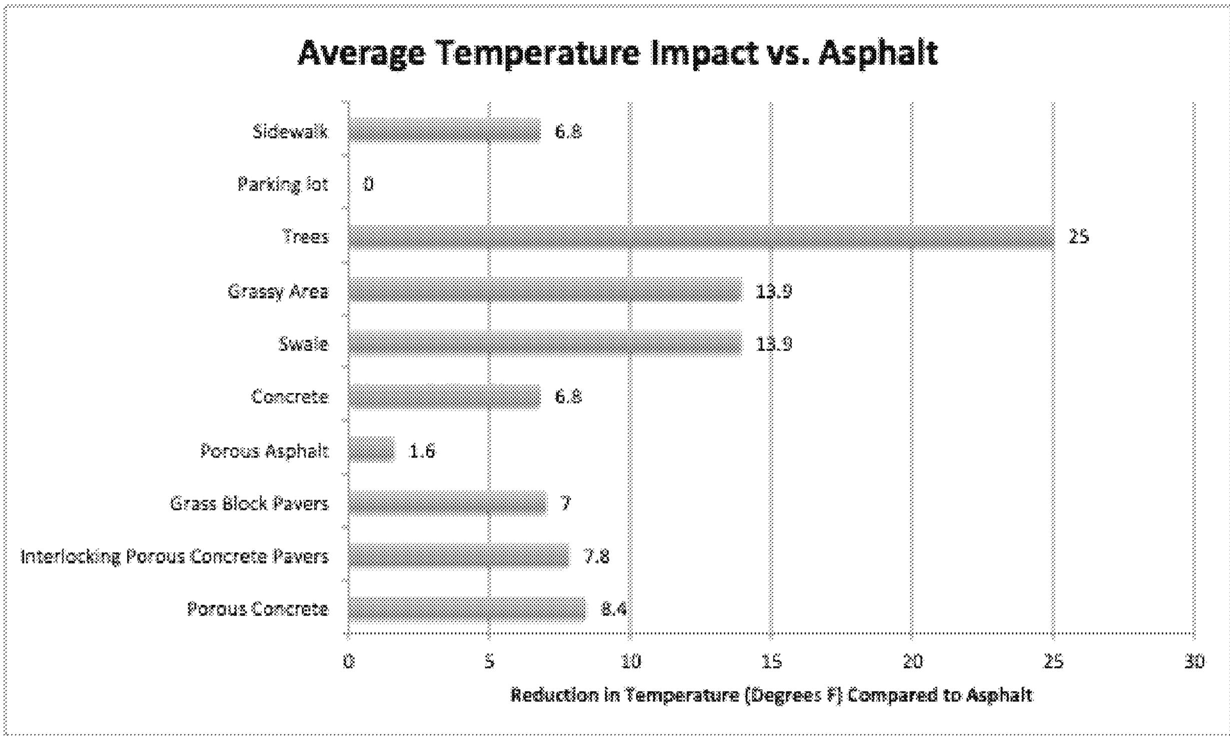

Figure 34: Temperature Changes from Land Cover Change

Using this link, the reduction in temperature is then used to determine avoided death over the life of the project. The reduction in the average annual mortality rate is uses the "higher emissions" scenario mean daily maximum temperature predictions for each month for the 30 years centered around 2050 taken from NOAA for the County[12], the local mortality rate (state-level), and the local (city-level) temperature threshold at which the impacts of heat on mortality can be detected (referred to as the Minimum Mortality Temperature, or MMT). Finally, the Value of Statistical Life, is used to quantify the benefit of reduced heat mortality rates.

8.3.2.2 Value of Statistical Life

The value of a statistical life (VSL) is used when analyzing the risk and reward trade-offs people make. Economists often estimate the VSL by looking at the risks that people take, or say they will take, and how much they are - or must be - paid for taking them. The VSL is widely used in the regulatory impact analysis and cost benefit studies for federal government cost benefit analyses (e.g. safety improvements in rail and roadways). A range of $5m-$13 million with a median around $9 million seems to be accepted. These values are in 2012 US Dollars and are adjusted for inflation depending on the year they are realized.

VSL is not intended to be the value of a specific life. It is the value placed on changes in the likelihood of death, not the price someone would pay to avoid death. Autocase does not place a dollar value on individual lives. Rather, the benefit-cost analysis of infrastructure uses estimates of how much people

[12] Temp in Fahrenheit: Jan = 68.27, Feb = 72.68, Mar = 78.68, Apr = 87.46, May = 96.59, Jun = 105.91, Jul = 108.39, Aug = 106.71, Sep = 102.24, Oct = 92.05, Nov = 78.19, Dec = 69.02

are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused or improved by the infrastructure.

References Used
(G. B. Anderson & Bell, 2011), (Basu, Feng, & Ostro, 2008), (Curriero et al., 2002), (Mercado, Hudischewskyj, Douglas, & Lundgren), (Medina-Ramon & Schwartz, 2007), (Sailor, 2003), (Zanobetti & Schwartz, 2008), (Voorhees et al., 2011), (NOAA, 2018).

8.3.2.3 Heat Island Effect (Morbidity)

Heat risk does not only affect risk of death, but also heat-related illnesses, which has a social cost in the form of lost productivity in an area. Estimating the value of heat-related illnesses follows a 4-step process:

1. Estimate temperature reduction from change in feature.
2. Estimate avoided heat-related illnesses from the resulting change in temperature.
3. Estimate cost of each heat-related illness
4. Combine, using relevant population for Phoenix.

Firstly, estimating the change in temperature resulting from feature change follows the same process as above for Heat Risk Mortality, details of which can be seen in Figure 34.

Secondly, estimating the change in heat-related illnesses resulting from the temperature change was created using data from Maricopa County. Using daily high temperatures and daily heat related illnesses for Maricopa County, a non-linear relationship between temperature and heat-related illnesses was calculated. From this data, we found that a 1 degree F reduction in temperature (from 102.4F to 101.4F) leads to 96.5 fewer heat-related illnesses per year in Maricopa County (population of roughly 4 million). Using Autocase, we can estimate the temperature reduction from GI/LID, and thus estimate the avoided illnesses per 100,000 people.

Thirdly, we have to calculate the cost of each heat-related illnesses. In order to estimate the social cost of illnesses, we used data from Maricopa County, which gave the percentage breakdown of the number of days spent in hospital due to heat-related illnesses, thus illustrating days out of work. From this, we estimate that the average cost of a heat related illness (in terms of lost wages, and thus lost economic output) is $3,046.

Finally, to calculate the final value, we firstly combine 1) the number of avoided heat-related illnesses per 100,000 people from GI/LID, and 2) the benefit of avoiding each illness, to estimate the value per 100,000 population. Then, applying the population of Phoenix (roughly 1.4 million), we can work out the total annual value for the City as a whole.

8.3.2.4 Avoided Flood Risk

Flood risk is quantified by estimating the percent flood risk mitigated as a result of the project design. As climate change has progressed and rainfall events in some regions have become more extreme, flood risk has become an important consideration in infrastructure development. Autocase quantifies the value of reduced flood risk due to a smaller volume of runoff from the project's property during storm events. Runoff can be reduced by increased green acreage, stormwater storage capacity, stormwater drainage capacity, or reducing the surface area covered by impervious land.

Flood risk is quantified in Autocase by estimating the percent flood risk mitigated in the city because of the project design. The components to this methodology are explained as follows:

1. The first is estimating the total flood risk damage in any given year.
   a. Flood risk is estimated based on historical property value and historical flood damage in each state in the United States.
2. The second component to the flood risk methodology is determining the flood risk mitigated because of the project.
   a. This uses historical rainfall data from over 6,000 weather stations across the United States and Canada, enabling location-specific rainfall data to estimate the rainfall amounts in large storm events each year. Precipitation trends from climate change predictions are also incorporated into the modeling using NOAA's climate explorer (NOAA, 2018).
   b. Estimated flood risk mitigated by the design is equal to the change in retention and infiltration capacity beyond the site's base capacity, divided by the approximate city-wide flood volume in storm events.
   c. The overall flood risk mitigated each year is calculated by multiplying total city property value by the flood risk mitigated.

Although the value at risk increases linearly when compared with storm repeat rate, this actually implies that risk increases exponentially as rainfall depth goes up. This is due to the fact that rainfall levels off as the storm repeat rate goes up. In other words, going from a 10-year storm to a 40-year storm may double rainfall depth from 2.5 inches to 5 inches, but that same doubling from 5 inches to 10 inches may be extremely improbable, even in a 10,000-year storm. In short, for each extra 0.1 inches of rainfall, flood damage is exponentially more costly.

The Autocase flood risk methodology is a dynamic simulation, meaning that for every year in each iteration of the simulation, it produces different risk values. For example, flood risk mitigated due to a decrease of impervious surfaces might be zero for most years. However, in some years there may be rainfall events that are extraordinarily large, at which point there could be massive flooding and the value of reduced flooding due to higher infiltration rates on the site may have value. This is reflected in the Autocase methodology, as there is an element of randomness applied to the rainfall estimates for each year. This means that Autocase's analysis is a better reflection of reality than assuming constant maximum storm strength each year or simply estimating reduced damage value from synthetic design storms, such as 10-, 20-, 50-, and 100-year storms.

References Used
(Hanson & Vogel, 2008); (Nowak & Greenfield, 2012); (Pielke, Downton, & Miller, 2002); (Cronshey, Roberts, & Miller, 1985), (NOAA, 2018).

8.3.2.5 Property Value Uplift/Aesthetic Value

The use of Green Infrastructure (GI) or Low Impact Development (LID) features can lead to increased property prices in a region. The "Property Uplift" benefit in Autocase provides a value estimate of a project's direct impacts on market prices. Most commonly, this value is derived from variations in housing prices, which in some part reflect the value of local environmental attributes. Increases in property values can result from the use of any of the following:

- Trees;
- Shrubs and other plantings;

- Bioretention;
- Rain gardens
- Dry detention pond;
- Infiltration trench;
- Lawn or grassy area;
- Porous pavement;
- Retention pond;
- Green roof;
- Wetlands.

Increased value can be attributed to improved aesthetic value of the local area, temperature-moderating effects of vegetation (thereby decreasing energy costs), reduced risk of flooding, or improved air quality. Many studies have quantified the potential impacts of LID projects on property prices. To estimate this benefit, city-wide average residential prices are used as the baseline property price. Property uplift is then applied to the baseline price to determine the property uplift value. After estimating the total property value increases, the estimate is then multiplied by 50% to account for possible double counting with other benefits included.

References Used
(Braden & Johnston, 2004); (L. M. Anderson & Cordell, 1988); (E. G. McPherson et al., 2006); (Ward, MacMullan, & Reich, 2008); (Wachter & Wong, 2008).

8.3.3 Environmental

8.3.3.1 Carbon Emissions

Newly planted trees, shrubs, grass, and plants can sequester carbon from the atmosphere, reducing the impacts of climate change. Additionally, growing trees, shrubs, grass, and plants can act as carbon 'sinks', absorbing carbon dioxide from the air and incorporating it into their stems or trunks, branches, and roots, as well as into the soil. As with air pollution, plant life often requires maintenance which emits carbon into the atmosphere.

Avoided CO_2 emissions, as well as increased CO_2 sequestration, is a benefit of investing in green infrastructure development. Relative to traditional gray infrastructure (e.g. pipes and water treatment infrastructure), LID may also have less embodied energy. In particular, the use of concrete is a large contributor to net embodied energy in gray infrastructure projects. However, in some cases - notably for green roofs - the net embodied energy may be higher than for traditional infrastructure due to differences in materials used or because more materials are needed.

Autocase quantifies the carbon sequestration rate for all design features in the software, given the available literature on carbon sequestration. It will then value this reduction in carbon emissions by applying the social cost of carbon to the change in total tonnes of avoided CO_2e emissions due to the project. The social cost of carbon used in this assessment follows the Interagency Working Group on Social Cost of Carbon and is valued at $ 41.68 per tonne.

References Used
(Interagency Working Group on Social Cost of Carbon, 2013), (Nordhaus, 2011), (Stern, 2006), (U.S. Energy Information Administration, 2011), (U.S. Environmental Protection Agency, 2013), (U.S. Environmental Protection Agency, 2014).

8.3.3.2 Air Pollution

For the purposes of this study, Criteria Air Contaminants (CACs) are considered air pollutants emitted by combustion engines, which affect the health of people immediately in their vicinity. Air pollution, or CACs, is removed from the environment by trees and shrubs. As these grow throughout the life of the project they capture air pollutants at an increasing rate.

The air pollutants reduced on site include mono-nitrogen oxides (NOx), sulphur dioxide (SO_2), volatile organic compounds (VOCs), and particulate matter smaller than 2.5 micrometers ($PM_{2.5}$). The air pollution is valued by multiplying by the social cost of each pollutant ranges from $6,730/tonne for NOx to $14,190/tonne for $PM_{2.5}$.

Table 47: Social Cost of Pollutants

Variable	Unit	Value
CO	$ per Metric Ton	$30.48
SO_2	$ per Metric Ton	$48,168
NO_2	$ per Metric Ton	$8,150
$PM_{2.5}$	$ per Metric Ton	$372,815
O_3	$ per Metric Ton	$1,442

References Used
(Cai, Wang, Elgowainy, & Han, 2012), (European Comission, 2005), (Mike Holland, 2002), (Friedrich, Rabl, & Spadaro, 2001), (Matthews & Lave, 2000), (G. E. McPherson, Nowak, & Rowntree, 1994), (Muller & Mendelsohn, 2010), (U.S. Environmental Protection Agency, 2014).

8.3.3.3 Avoided Air Pollution and Carbon Emissions due to Reduced Energy Use

Trees modify climate and conserve building energy use in three principal ways:

1. Shading—reduces the amount of radiant energy absorbed and stored by built surfaces.
2. Transpiration—converts liquid water to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
3. Wind speed reduction—reduces the infiltration of outside air into interior spaces and conductive heat loss, especially where thermal conductivity is relatively high.

Trees provide greater energy savings in the Desert Southwest region than in milder climate regions because of the long, hot summers. Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production. Autocase then uses the same principal as above to calculate the avoided emissions and the resulting social benefit from that.

The work by (G. McPherson et al., 2004) estimate that public trees save 77-181 kWh per year in electricity and around 229 kBTU in natural gas.
Applying this to our case study sites:

- For the Central Station LID design, there are 44 trees (44*180 kWh = 7,920 kWh saved per year and 44*229 =10,076 kBTU saved per year). For the traditional design, we assume 34 trees (34*180 kWh = 6,120 kWh and 34*229kBTU = 7,786 kBTU saved per year)

- Primera Iglesia LID design has 15 trees, resulting in an estimated annual saving of 2,700 kWh and 3,435 kBTU. The base case would have had no trees, and thus no resulting energy or natural gas savings.
- The Glendale site has 8 trees, resulting in an estimated annual saving of 1,440 kWh and 1,832 kBTU. The base case would have had no trees, and thus no resulting energy or natural gas savings.

References Used
McPherson E.G., J.R. Simpson, , J.R.; Peper, P.J.; Maco, S.E.; Xiao, Q.; Mulrean, E. 2004. Desert Southwest Community Tree Guide: Benefits, Costs and Strategic Planting. Arizona Community Tree Council, Inc. Phoenix, AZ. 76 p.

8.3.3.4 Water Quality

Increased acres of vegetation, including forests or wetlands, can positively influence the water quality in a local area by reducing surface runoff of pollutants into local waters.

Phoenix has a separate storm sewer system, so runoff does not get treated by a wastewater treatment plant (WWTP). Most stormwater in Phoenix goes directly to a surface water (dry wash, river, or retention basin) untreated. Per Section 6.8 of the City of Phoenix Stormwater Policies and Standards Manual (2013), developments are required to "retain water from the 100-year, 2-hour duration storm falling within property boundaries" or provide "first flush" stormwater treatment. In the latter case, first flush runoff may pass through either a hydrodynamic separator or a filter catch basin insert before going in to the storm system.

Hydrodynamic separators use the energy of flowing water to help separate out sediments, as opposed to more traditional settling chambers, and is designed to capture settleable solids, floatables, oil and grease.

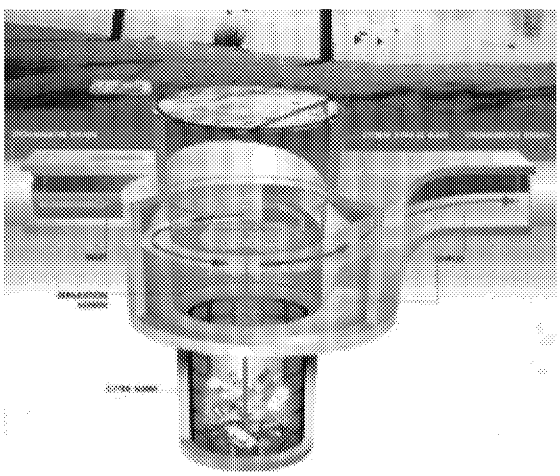

Figure 35: Hydrodynamic Separator
Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".

Filter catch basin inserts consist of a deep basket with a fabric liner that filters the storm water. In addition, oil absorbent pads are placed in the basket for removal of petroleum hydrocarbons. The inserts are held in place by the catch basin grate. Typically, the filter is specifically designed to fit the Maricopa Association of Governments (MAG) catch basin and can be inserted directly into existing catch basins.

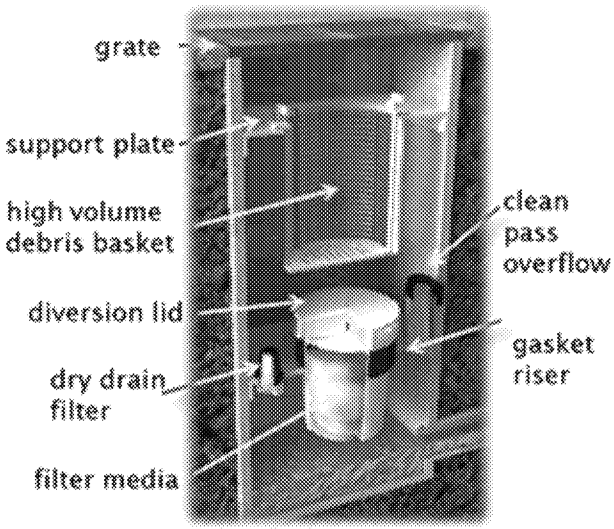

Figure 36: Catch Basin Filter Insert
Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".

We model the value of improved water quality by estimating the reduced runoff that would be passing through these gray systems due to having LID present on the site (and the water passing through the LID before reaching these systems) and equate that to the cost avoided in CapEx and O&M for the gray system. Historical rainfall are supplemented by NOAA's RCP8.5 climate predictions (NOAA, 2018).

The model calculations are given in the tables that follow. Cost data was provided by the City of Phoenix for each system, which is given in the table below.

Table 48: Cost Information for Filter Catch Basin Inserts and Hydrodynamic Separator

	Low	**Medium**	**High**
System	No system	Filter catch basin insert	4-foot Hydrodynamic separators
System size acreage	N/A	1.16	1.16
CapEx ($)	$0	-$900	-$16,000
O&M ($ per year)	$0	-$500	-$2000
Useful life (year)	N/A	30	30

Notes:
The lifecycle cost information was provided by the City from a recent project at the City 22nd Ave Service Center, 2441 S 22nd Ave.

From these inputs, we calculated the present value of the lifecycle costs over a 50-year period to estimate the total cost of ownership of each system, results of which are in *Table 49*.

Table 49: Lifecycle Cost (Total Cost of Ownership) of Each System

	Lifecycle costs (present value over 50 years)		
	Low	**Medium**	**High**
System	Filter catch basin insert	Filter catch basin insert	4-foot Hydrodynamic separators
CapEx	$0	-$900	-$16,000
O&M	$0	-$12,500	-$24,200
Residual value	$0	$66	$170
Replacement cost	$0	-$360	-$1,960
Total cost	$0	-$13,694	-$41,990

Notes:
The costs are just for the systems themselves and do not include installation, concrete removal or replacement that may be needed on top of that.

After calculating the present value of lifecycle costs, we then determine the size of system needed in the base case. For example, if one system is designed for 1.16 acres, then on a per square foot basis, 0.3 systems are needed for the 15,000 sq ft (0.344 acres) drainage area we are using for the general feature analysis. We then calculate the reduced runoff passing through the system due to each LID being implemented for the 15,000 sq ft drainage area and estimate the resulting number of systems that would be needed. For example, if the LID halves the runoff, we would need half the system. We then find the corresponding system cost for the design case. Finding the difference in cost between the amount of system needed in the base case and the cost for the amount of system needed under the LID scenario is the value of water quality. The results are summarized in Table 50.

The low cost corresponds to no system being put in place, the medium cost is for the filter catch basin insert covering 1.16 acres, and the high estimate is for the 4-foot hydrodynamic separator covering 1.16 acres.

Table 50: Water Quality Valuation Method for Phoenix

		Conc	Swale	Por conc	Bio basin	Inf tren	IPCP	Por asph	PI	Glen	C/C/T trad	C/C/T LID
Number of systems needed for 15,000 sq ft base case.		0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.49	8.88	8.88
Cost of system for base case	Low	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Med	$4,065	$4,065	$4,065	$4,065	$4,065	$4,065	$4,065	$5,419	$6,775	$121,593	$121,593
	High	$12,465	$12,465	$12,465	$12,465	$12,465	$12,465	$12,465	$16,615	$20,774	$372,842	$372,842
Runoff in LID scenario as a % of runoff in base case		100%	42%	58%	43%	64%	58%	58%	11%	12%	75%	8%
Number of systems needed for 15,000 sq ft with 1,000 sq ft LID.		0.30	0.12	0.17	0.13	0.19	0.17	0.17	0.04	0.06	6.70	0.75
Cost of system with LID	Low	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Med	$4,065	$1,697	$2,377	$1,744	$2,599	$2,377	$2,377	$612	$823	$91,776	$10,269
	High	$12,465	$5,203	$7,289	$5,348	$7,968	$7,290	$7,290	$1,876	$2,523	$281,414	$31,486
Savings from LID	Low	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Med	$0	$2,368	$1,688	$2,321	$1,466	$1,688	$1,688	$4,807	$5,952	$29,817	$111,325
	High	$0	$7,262	$5,175	$7,117	$4,497	$5,175	$5,175	$14,739	$18,252	$91,428	$341,356

Notes:
Conc = Concrete, Swale = Swale, Por conc = Porous Concrete, Bio basin = Bioretention basin, Inf tren = Infiltration trench, ICPC = Pervious pavers, Por asph = Porous Asphalt, PI = Primera Iglesia, Glen = Glendale Community Center, C/C/T trad = Central/Civic/Taylor traditional design, C/C/T LID = Central/Civic/Taylor LID design.

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10 Appendices

10.1 Appendix A: Feature Type Results Breakdown with Design Storm Sensitivity

The following table shows the breakdown by impact type when the 24-hour design storm is varied. As outlined earlier in the report, the results in the body of the report are for a 1-inch 24-hour storm, but the table below also shows results for 0.5-inch and 2-inch storms.

In Autocase, the design storm only affects the additional piping and detention impacts (CapEx and O&M). If a feature type can absorb all three storms, then there should be no change.

As we can see in Table 51, all the feature types have the same savings versus Concrete for CapEx and O&M on additional piping and detention.

Table 51: Storm Sensitivity Results for GI/LID Feature Types

Feature/Site	Design Storm	CapEx on Additional Detention	O&M on Additional Detention	CapEx on Additional Piping	O&M on Additional Piping
Swale	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Bioretention basin	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Infiltration trench	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Pervious pavers	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Porous concrete	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76
Porous asphalt	0.5-inch	$24	$6	$505	$76
	1-inch	$24	$6	$505	$76
	2-inch	$24	$6	$505	$76

10.2 Appendix B: Case Sites Results Breakdown with Design Storm Sensitivity

The following table shows the breakdown by impact type when the 24-hour design storm is varied. As outlined earlier in the report, the results in the body of the report are for a 1-inch 24-hour storm, but the table below also shows results for 0.5-inch and 2-inch storms.

In Autocase, the design storm only affects the additional piping and detention impacts (CapEx and O&M). If a feature type can absorb all three storms, then there should be no change.

As we can see in Table 52, Primera Iglesia does not have any savings under the 0.5-inch design storm versus its base case. However, under the 1-inch design storm there are savings of roughly $900. This increases to around $3,200 under the 2-inch design storm, indicating the avoided need to use additional piping and detention.

For Glendale Community Center, there are zero savings versus the base case under the 0.5-inch design storm. Under the 1-inch and 2-inch design storms, there is roughly $1,200 and $4,000, respectively in savings from avoiding having to use additional piping and detention.

Lastly, for Central/Civic/Taylor, we can see that there are zero savings under each design storm, indicating that there is already enough capacity under the base case design i.e. the LID design does not avoid any additional piping and detention.

Table 52: Storm Sensitivity Results for Case Study Sites

Feature/Site	Design Storm	CapEx on Additional Detention	O&M on Additional Detention	CapEx on Additional Piping	O&M on Additional Piping
Primera Iglesia	0.5-inch	$0	$0	$1	$0
	1-inch	$36	$9	$769	$114
	2-inch	$237	$60	$2,516	$372
Glendale Community Center	0.5-inch	$0	$0	$1	$0
	1-inch	$46	$12	$973	$144
	2-inch	$301	$76	$3,187	$471
Central/Civic/ Taylor	0.5-inch	$0	$0	$0	$0
	1-inch	$0	$0	$0	$0
	2-inch	$0	$0	$0	$0